Weed Science, 53:130–137. 2005

Input–output modeling, outdoor recreation, and the economic impacts of weeds

Mark E. Eisworth
Corresponding author. Department of Economics, College of Business and Economics, University of Wisconsin, Whitewater, WI 53190; eiswertm@uww.edu

Tim D. Darden
New Mexico Department of Agriculture, MSC 3189, Box 30005, Las Cruces, NM 88003

Wayne S. Johnson
Department of Resource Economics, University of Nevada, Reno, NV 89557

Jeanmarie Agapoff
Farm Service Agency, U.S. Department of Agriculture, 1400 Independence Avenue S.W., Washington, D.C. 20250

Thomas R. Harris
Department of Resource Economics, University of Nevada, Reno, NV 89557

Nonindigenous invasive weed species can have substantial negative impacts on the quantity and quality of outdoor recreational activities such as fishing, hunting, hiking, wildlife viewing, and water-based recreation. Despite the significance of impacts on recreation, very little research has been performed to estimate the corresponding economic losses at spatial scales such as regions, states, and watersheds. This is true primarily because in most jurisdictions the data necessary to estimate recreational impacts are scarce and incomplete. Because of the challenges involved in measuring recreational losses precisely, we illustrate a method that can provide indications of the ranges in which the true economic losses likely lie. To reflect underlying uncertainty in parameters such as the number of acres infested in a jurisdiction and the rate at which wildlife-related recreation decreases as a function of increasing weed infestation, we developed a range of estimates using lower, medium, and higher scenario combinations of parameter and variable values. Our case study jurisdiction is a western state (Nevada) in which nonindigenous weed infestations on public lands have expanded rapidly in recent years. Under conservative assumptions, the negative economic impacts stemming from the adverse influence of nonindigenous weeds on wildlife-related recreation in Nevada likely range from $6 million to $12 million per year. Using the most conservative findings for annual recreation losses, the predicted discounted stream of negative economic impacts over a future time horizon of 5 yr ranges from about $30 million to $40 million in Nevada, depending on actual future expansion rates of weeds.

Key words: Economic impacts, input–output analysis, invasive weeds, nonindigenous species, recreation.

Nonindigenous invasive weed species can have substantial impacts on recreational activities such as fishing, hunting, hiking, wildlife viewing, and water-based recreation. Invasive species alter ecosystems. They negatively affect a wide array of environmental attributes that are important to support recreation, including but not limited to soil quality (Olson 1999), water quality and quantity (Bell 1996; Sala et al. 1996), plant diversity (Olson 1999; Young and Longland 1996), availability of forage and cover (Bell 1996; Olson 1999), and animal diversity and abundance (Olson 1999).

Perhaps the most obvious impacts of invasive weeds and plants on recreation occur in riparian areas, not only because the rate of spread is rapid in these areas but also because large volumes of recreational activity are centered around waterways and the animal habitats surrounding them. Watersheds support water-based recreation such as swimming and boating, as well as fish and wildlife populations that in turn support fishing, hunting, and wildlife viewing. Prominent invasive weeds such as saltcedar (*Tamarix ramosissima* Ledeb.), purple loosestrife (*Lythrum salicaria* L.), and perennial pepperweed (*Lepidium latifolium* L.), all invade riparian areas with great potential to spread at rapid rates (Smith et al. 1999). In addition, aquatic weeds such as hydrilla [*Hydrilla verticillata* (L.f.) Royle] and Eurasian watermilfoil (*Myriophyllum spicatum* L.) in many instances cause severe impacts on water-based recreation by impeding human access, interfering with the operation of watercraft and fishing lines, lowering water quality, and negatively altering aquatic ecosystems, including the abundance and diversity of fish (Eiswerth et al. 2000; Madsen 1997; Madsen et al. 1991; Newroth 1985).

The invasion of upland areas by nonindigenous annual grasses and perennial weeds poses potential impacts on recreation as well. For example, the negative ecological impacts in the western United States of nonindigenous invasive annual grasses such as downy brome (*Bromus tectorum* L.) and red brome (*Bromus rubens* L.), and the strong link between wildfires and subsequent invasive annual grass dominance, are well documented (D'Antonio and Vitousek 1992; Larson and Sheley 1994; Mack 1981; Rosentrater 1994). More serious than the direct impacts of the invasive annual grasses themselves, annual grass–dominated communities are open plant systems easily invaded by "the next weed that is introduced" (Young and Longland 1996), with examples including invasions by medusahead [*Taeniatherum caput-medusae* (L.) Nevski] (McKell et al. 1962) and bur buttercup (*Ranunculus testiculatus* Crantz) (Young et al. 1992). Other weeds capable of invading such communities include spotted knapweed (*Centaurea maculosa* Lam.), diffuse knapweed (*Centaurea diffusa* Lam.), Russian knapweed [*Acroptilon repens* (L.) DC.] (Roche and Roche 1991, 1999; Sheley et al. 1999b; Whitson 1999), yellow starthistle (*Centaurea solstitialis* L.) (Roche and Thill 2001), and rush skeletonweed (*Chondrilla juncea* L.) (Sheley et al. 1999a). Such perennial invasive weeds significantly alter ecosystems and specifically reduce the amount of forage and cover available (Olson 1999), with resultant negative impacts on wildlife-associated recreation.

Despite the significance of impacts on human recreation,

Table 1. Annual recreation expenditures in Nevada (millions of dollars).[a,b]

Recreation activity	Trip-related expenditures yr^{-1}	Equipment expenditures yr^{-1}	Expenditures yr^{-1} for other items	Total expenditures yr^{-1}
Hunting	$22.8	$74.3	$7.2	$104.2
Fishing	$81.2	$142.1	$8.5	$231.8
Wildlife watching	$94.6	$184.6	$9.4	$288.6
Total	$198.6	$401.0	$25.1	$624.6

[a] Source: USFWS (1996).
[b] All values have been updated to June 2000 U.S. dollars.

very little research has been conducted to estimate the corresponding economic losses. The few examples to date (including Leistritz et al. 1992; Leitch et al. 1996) comprise cases in which the analysis of recreation losses has been (1) one part of a broader effort that also examines economic impacts from reduced grazing, (2) focused on one or a very small number of weed species that have already yielded substantial and conspicuous economic impacts in a state or region, or (3) facilitated by the availability of good mapping (and other collected) data.

Several different types of information are required to estimate the ecological and economic impacts caused by nonindigenous invasive weeds. Because of the logistic challenges and considerable expense involved with data collection, gaps in desired data and uncertainty in key parameters represent the norm rather than the exception. Despite data deficiencies, it is quite important to develop best estimates of the ranges in which invasive weed economic impacts likely lie. The development of such estimates can support land managers, land owners, and decisionmakers at all levels of government in making choices regarding the allocation of financial resources toward weed control efforts. Economic impacts from impaired outdoor recreation opportunities are likely relatively large in many jurisdictions. However, entities that devote resources to managing invasive weeds (State agencies and legislatures, weed districts, counties, etc.) are faced with a broad portfolio of pressing needs with which decisions to invest in weed management must compete. Research on the economic losses imposed by nonnative weeds can help place the problem in perspective relative to other environmental and public policy issues, prioritize needs across jurisdictions and species, and identify economically efficient levels of weed management.

For many regions, states, watersheds, etc., researchers do not have the luxury of access to high-quality data such as (1) complete weed-mapping data, (2) invasive weed percentage cover data, and (3) reliable, site-specific information on how recreators respond (e.g., by visiting a site less often or by enjoying their recreation less) when a nonnative weed invades an area. At the same time, the demands for estimates of economic impacts from nonindigenous species are on the rise and emanate from many sources.

The objective of this research was to estimate the economic impacts that invasive weeds have, through their effects on outdoor recreation, in a particular geographic area when the data desired to do so are scarce or of low quality.

Materials and Methods

General Approach

Our approach to estimating economic impacts of invasive weeds in the face of significant data gaps is characterized by two attributes. First, in the absence of "bottom-up" case studies for geographic subunits (such as individual state parks, national forest recreation areas, river stretches, or hunting subunits), it applies "top-down" analysis to aggregated state-level data. Our application is to a western state (Nevada) in which a number of nonindigenous invasive weeds are spreading at rapid rates and negatively affecting recreational activities in both riparian and upland areas. Second, our approach acknowledges (and reflects) uncertainty in the available data by estimating a range of potential recreation losses rather than producing a misleading point estimate. Other impacts of nonindigenous weeds and plants (e.g., on grazing, cropping, water provision, and ecosystem services more broadly considered) of course are important in Nevada and other states. However, this article focuses solely on recreational impacts.

Data

Consumer expenditure data are commonly used by economists who wish to estimate the impact of a change in human behavior or environmental characteristics on the economy of a particular region or state. To do this, economists use an "expenditure-based approach" to model the impacts of changes in consumer spending as the impacts ripple through the economy. State-level data on the magnitudes of expenditures on (1) fishing, (2) hunting, and (3) wildlife-watching activities are collected every few years by the U.S. Fish and Wildlife Service and U.S. Bureau of the Census. Table 1 shows these expenditure figures for Nevada, updated to Year 2000 dollars, from the most recently available survey (USFWS 1996). The total expenditure per year on these types of recreation is estimated to be about $625 million.

Weed-mapping efforts and analysis are underway in Nevada but at this stage provide neither a good nor complete indication of infestation rates in the state. To estimate infestation rates for our study, an expert opinion telephone survey was conducted by researchers at the University of Nevada, Reno (M. E. Eiswerth, W. S. Johnson, and A. Auton, unpublished data). The sample frame included weed and conservation district managers, Bureau of Land Management (BLM) specialists dealing with invasive weeds in BLM districts, the U.S. Forest Service (USFS), and Indian tribe and The Nature Conservancy specialists involved in invasive weed management or analysis. Basically, we surveyed those responsible for weed management at every BLM district in the state, USFS districts in the state, and weed and conservation district managers (the size of these districts varies) across Nevada. Survey respondents were asked the following question: "Can you estimate about how many acres, or what percent of total acres, are infested with invasive weeds in these (your jurisdiction's) watersheds?" We received responses to this question from 22 respondent–watershed combinations (many watersheds have multiple management, so we received estimates from more than one respondent for some watersheds), with five additional attempted respondents failing to provide estimates for this question. The mean response for percentage of area infested was 46%. This primary study provided an indication of the mean value of infestation rates in Nevada watersheds.

Estimation Techniques

To address the feature of uncertainty in key parameters and variables, we use the practice of developing "lower," "middle," and "higher" estimates of annual losses from invasive plants and weeds. This practice, standard in applications such as environmental benefit–cost analysis and natural resource damage assessment (NRDA), helps reflect uncertainty in the analysis, yields a "bounding exercise," and provides a better indication (than a point estimate) of the likely range of potential losses.

We use input–output (I/O) analysis to estimate the economic impacts that weeds yield by way of reductions in outdoor recreation. The I/O analysis is a valuable tool that has been used in a number of different contexts to estimate the economic impacts of a change or "shock" to a local, state, or regional economy. An I/O model is essentially a mathematical representation of the purchases and sales patterns of a regional economy. The model is used to estimate total regional impacts to output, employment, and income at a given point in time. The total impact of any shock to the economy consists of direct, indirect, and induced impacts. Direct impacts are those activities or changes in production level of the affected industries (in this case, retail and service sectors affected by changes in recreational spending). Indirect impacts occur throughout the economy as a result of providing goods and services to the affected industries. Induced impacts are those impacts caused by changes in household consumption as a result of the direct and indirect impacts.

To carry out the I/O modeling we used Impact Analysis for Planning (IMPLAN), an over-the-counter I/O model (Minnesota IMPLAN Group Inc. 2000). The model estimates impacts on the basis of the estimated reduced recreation spending brought about by invasive weeds. The basic components that comprise the I/O model are the employment, output, and income generated from each sector in the economy. The total employment figures are based on Regional Economic Information System (REIS) data (U.S. Department of Commerce 2001) and are full- or part-time employees in a given sector. Sectoral income is derived by the summation of wages and salaries paid to employees plus the proprietors' income, which also is based on the REIS data. Output is simply the gross sales for nonagricultural industries and gross value of production for agricultural products.

The final demand requirements are the basis for the I/O model framework. These figures make up the multipliers, which in turn are the main mechanisms from which all impacts are generated within the I/O framework. When a (U.S.) dollar enters the economy, part of that dollar remains in the economy and part of it leaves in the form of savings or as payment for imported goods. By dividing $1 worth of initial output (or change in output) by the output multiplier, for instance a final demand multiplier of 1.42, the first transaction yields $0.70 leaving the economy and $0.30 staying in the economy. Dividing the remaining $0.30 that stays in the economy by the same multiplier of 1.42 yields $0.21 ($0.30/1.42 = $0.21) leaving the economy and $0.09 ($0.30 − $0.21 = $0.09) staying within the economy in the second round. These steps are repeated in subsequent impact rounds until the amounts staying within the economy have disappeared. Adding all the amounts calculated as staying in the economy plus the original dollar yields the multiplier of 1.42. These multipliers are created for output, income, and employment using complex matrix operations based on a Leontief input–output model as explained in Miller and Blair (1985).

Losses in direct recreation expenditures, the starting point for the I/O analysis, are calculated according to the following equation

$$\mathrm{RE} = (\eta)(\phi)(\mathrm{CE} + \mathrm{RE}), \qquad [1]$$

which may be solved for RE as

$$\mathrm{RE} = (\eta)(\phi)(\mathrm{CE})/(1 - \eta\phi), \qquad [2]$$

where RE = reduced expenditures (reductions in wildlife-based recreational direct expenditures due to nonindigenous invasive weeds), CE = current expenditures (current wildlife-based recreational direct expenditures), (CE + RE) = potential (baseline) wildlife-based recreational direct expenditures in the absence of any nonindigenous invasive weed infestations, η = the rate at which wildlife recreation expenditures are reduced when land is infested with nonindigenous weeds, $0 < \eta < 1$, ϕ = fraction of potential recreation lands that currently are infested with nonindigenous invasive weeds, $0 < \phi < 1$.

Note that, in Equation 1, the linkage parameters η and ϕ are multiplied by the sum of current recreation use values and estimated losses rather than solely current observed recreation values. This is to indicate and account for the concept of "baseline recreation" or the magnitude of recreation that would take place in an area without any invasive plants and weeds. Although arranging the calculation in this way makes little difference empirically, the structure of the equation correctly reflects the premise that because nonindigenous weeds and plants are already present in Nevada, current recreation magnitudes already lie below the baseline (of full potential recreation in the absence of nonindigenous weeds). Hence, the baseline is not directly observable. Further expansions of nonindigenous weeds will lead to additional depressions of recreational quantity and quality below the baseline.

Current wildlife-related recreation expenditures (CE) are $599.6 million and simply correspond to total recreation expenditures less "expenditures for other items" (approx. $625 million minus $25 million, see Table 1). The category "expenditures for other items" was not included in the calculations because it consists largely of payments to government (e.g., licenses, permits, tags) and items such as membership dues and magazine subscriptions. These types of expenditures are not injected into the state's economy and thus are not included because the focus of the I/O analysis is to examine economic impacts at the state level.

Little investigation has been undertaken to provide information on the values of key parameters that (1) are impor-

TABLE 2. Parameter values used as inputs for the input–output model impact estimates.[a]

Parameter[b]	Scenario estimate		
	Lower	Middle	Higher
η	0.12	0.17	0.22
ϕ	0.35	0.50	0.65

[a] All values have been updated to June 2000 U.S. dollars.

[b] The parameter η denotes the percentage decrease in wildlife-related recreation expenditures that results from a 1% increase in weed infestation. The parameter ϕ denotes the fraction of potential recreation lands that are currently infested with nonindigenous invasive weeds. These parameters are used to calculate invasive weed–induced reductions in wildlife-based recreational expenditures (RE) according to the equation RE = $(\eta)(\phi)(CE)/(1 - \eta\phi)$, where CE represents current expenditures.

tant for estimating the economic costs of nonnative weeds (especially through complicated mechanisms such as reduced outdoor recreation) and (2) vary across geographic settings and types of weeds. Regarding η, no studies to measure its value have been undertaken in our case study area (Nevada), and the most closely related studies are those dealing with the linkage between leafy spurge (*Euphorbia esula* L.) infestation rates and declines in recreation activity in the northern Great Plains (Leitch et al. 1996). Leitch et al. (1996) estimated (among other results, such as grazing impacts) the losses in wildlife-related recreation expenditures due to leafy spurge in Montana, North Dakota, South Dakota, and Wyoming. For leafy spurge alone, annual wildlife-related recreation expenditure losses ranged from $19,000 for Wyoming to North Dakota's $2.1 million (1993 dollars). From these reported losses, a reasonable range of values for our parameter η can be derived that indicate the incremental impact of invasive weed species on recreational expenditures for each state. We use their results for Montana and Wyoming, assuming that these two states are closest in landscape characteristics to Nevada. The parameter η denotes the average percent reduction in recreation expenditures per 1% increase in weed infestation (on a scale from 0 to 100% infestation).

To develop a lower scenario estimate of η, we use the Leitch et al. (1996) results for Montana, from which we calculate that wildlife-related recreation expenditures are reduced (on average) approximately $1.49 million (updated to 2000 dollars) for each 1% increase in total land area infested. On the basis of recreation expenditure data for Montana (USFWS 1996), this translates to a 0.12% decrease in recreation spending for each 1% increase in total land area infested (η = 0.12). For the higher scenario estimate, we use the Leitch et al. (1996) result for Wyoming of a 0.22% reduction in recreation spending from a 1% increase in infestation rate (η = 0.22). For the middle scenario, we use the midpoint of the lower and higher parameter values (η = 0.17).

The parameter ϕ denotes the fraction of potential recreation lands that are currently infested with nonindigenous invasive weeds. We use the value of 0.50, which is approximately the average value obtained from the Nevada survey (0.46), as discussed above, as the midpoint of our parameter range (M. E. Eisworth, W. S. Johnson, and A. Auton, unpublished data). Low and high scenario values of ϕ were set to 0.35 (30% lower than the midpoint) and 0.65 (30% higher than the midpoint). This range is based on our professional judgment regarding a reasonable band of uncertainty around the mean rather than a statistical confidence interval based on the parameters required to construct such an interval (i.e., the true standard deviation and the form of the underlying distribution) because good information on these parameters typically is not available. A summary of the parameter values used for η and ϕ, for each of the three estimation scenarios, is shown in Table 2.

Substitution of the ϕ and η parameter values discussed above into Equation 2 yields lower, middle, and higher scenario values for RE, annual reductions in wildlife-based recreational direct expenditures due to weeds. These lower, middle, and higher scenario values for RE are about $26 million, $56 million, and $100 million, respectively (Table 3).

Next, we estimated the portion of these recreation expenditure losses attributable to reductions in recreation spending by out-of-state residents. We do this because the objective of the I/O analysis is to estimate the economic impacts within the state of Nevada. To our knowledge, no reliable data exists regarding the link between weed infestations in Nevada and the extent to which state residents tend to switch to recreation sites outside of Nevada in response to such infestations. Therefore, to be conservative in estimating impacts, we assume that in-state residents respond to infestations either (a) by switching to substitute, noninfested recreation sites within the state or (b) by diverting spending from wildlife-related recreation to other forms of expenditure within the state (e.g., movies, concerts, other forms of entertainment). Under this conservative assumption (i.e., if anything, it may lead to an understatement of economic impacts), we consider in the I/O analysis only the estimated decline in wildlife-related recreation spending by nonresidents. Using data regarding the numbers of recreation days accounted for by Nevada state residents vs. nonresidents (USFWS 1996), we calculate that 17% of the total recreation days in Nevada are attributable to out-of-state visitors. We apply this percentage to the calculated losses in total direct expenditures (Row 1, Table 3) to derive the estimated nonresident direct expenditure losses (Row 2, Table 3). To the extent that some nonresidents respond to an infestation by switching to a substitute site within Nevada, declines in nonresident expenditures will be overstated. However, our conservative treatment of in-state recreator expenditures

TABLE 3. Direct expenditure losses used in the I/O model.[a]

Variable	Scenario estimate		
	Lower	Middle	Higher
RE	$26.3 million	$55.7 million	$100 million
Estimated nonresident direct expenditure losses	$4.47 million	$9.47 million	$17.0 million

[a] Abbreviations: I/O, input–output RE, direct losses (reduced recreational expenditures).

TABLE 4. Lower scenario estimate of the impacts of a weed-induced reduction in recreational expenditures to the State of Nevada's economy (millions of $).

Expenditure loss (U.S.$ millions)	−$4.47	Retail/service sector split	Estimated direct impacts
Retail trade sector expenditures	67%	−$3.00	−$0.95
Service sector expenditures	33%	−$1.48	−$1.48
Retail trade margin	31.8%		
	Direct impacts	Indirect/induced impacts	Total impacts
Total industry impacts	−$2.43	−$1.70	−$4.13
Total labor income impacts	−$1.10	−$0.62	−$1.73
Total economic impacts	−$3.53	−$2.32	−$5.85
Total employment impacts (number of jobs)	−40	−21	−61

(noted above) will more than counterbalance such a potential overstatement given the relatively small level of nonresident expenditures as a percent of the total.

The reductions in nonresident direct expenditures were then broken down specifically into retail trade purchases and service sector purchases at the rate of 67 and 33%, respectively. We used this ratio, used by Bangsund et al. (1999) to estimate economic impacts from biological control of leafy spurge in the northern Great Plains because of the lack of primary survey data indicating the allocation of wildlife-associated recreation expenditures specifically for Nevada. Allocating expenditures between these two sectors was done to better estimate the regional economic impacts of how those dollar purchases flow throughout the economy and affect regional employment and income.

Purchases made from the retail trade sector were margined at a rate of 31.8% to capture only the retail markup of goods purchased. The retail trade margin used was an average of all retail sectors from the Bureau of Census Annual Survey of Retail Trade (U.S. Bureau of the Census 2000). The margined figure allows only the impacts of the retail trade purchases rather than total purchases by the retail sector for resale, which would overstate the overall impact on the regional economy.

The final result of the I/O modeling is annual negative economic impacts of a weed-induced reduction in recreational expenditures. We then used these estimates of annual impacts to estimate future flows (for a 5-yr time horizon) of economic impacts, under various infestation expansion rates. Future economic impacts were discounted at an interest rate of 4% to place all estimates in present value terms, according to

$$PV = FV/(1 + r)^t \quad [3]$$

where PV and FV denote present and future values, respectively, r is the discount rate, and t is the number of years from the present period.

Results and Discussion

Using lower scenario values for each of the parameters and variables discussed in the Materials and Methods section illustrates a conservative picture of the economic impacts of nonindigenous weed infestation (through depressed recreational activity only) to Nevada's economy (Table 4). The starting point in Table 4, −$4.47 million direct expenditure loss, originates from the estimated nonresident direct expenditure losses shown in Table 3 for the lower scenario. This starting point was used to estimate the income, employment, and indirect/induced impacts to Nevada's economy. The industry impacts amount to a total of −$4.13 million, apportioned between direct impacts (−$2.43 million) and indirect/induced impacts (−$1.70 million). The labor income impact amounts to a total of −$1.73 million, with −$1.1 million in direct income losses and −$0.62 million in indirect and induced losses. Along with the industry and labor income impacts, there is a loss of 61 jobs, expressed as either full- or part-time jobs (not full-time equivalents). The total economic impacts for the lower scenario in Table 4 amount to about −$5.9 million yr^{-1} which includes all direct and indirect/induced impacts.

The middle and higher scenario estimates of impacts on the state's economy are similarly summarized in Tables 5 and 6. The middle scenario estimate of total economic impacts is −$12.4 million yr^{-1} (Table 5), whereas the higher scenario estimate of total impacts is −$22.3 million yr^{-1} (Table 6). In the absence of more and better information

TABLE 5. Middle scenario estimate of the impacts of a weed-induced reduction in recreational expenditures to the State of Nevada's economy (millions of $).

Expenditure loss (U.S.$ millions)	−$9.47	Retail/service sector split	Estimated direct impacts
Retail trade sector expenditures	67%	−$6.34	−$2.02
Service sector expenditures	33%	−$3.13	−$3.13
Retail trade margin	31.8%		
	Direct impacts	Indirect/induced impacts	Total impacts
Total industry impacts	−$5.14	−$3.60	−$8.74
Total labor income impacts	−$2.33	−$1.32	−$3.65
Total economic impacts	−$7.48	−$4.92	−$12.40
Total employment impacts (number of jobs)	−85	−44	−129

Table 6. Higher scenario estimate of the impacts of a weed-induced reduction in recreational expenditures to the State of Nevada's economy (millions of $).

Expenditure loss (U.S.$ millions)	−$17.00	Retail/service sector split	Estimated direct impacts
Retail trade sector expenditures	67%	−$11.39	−$3.62
Service sector expenditures	33%	−$5.61	−$5.61
Retail trade margin	31.8%		
	Direct impacts	Indirect/induced impacts	Total impacts
Total industry impacts	−$9.23	−$6.47	−$15.70
Total labor income impacts	−$4.19	−$2.37	−$6.56
Total economic impacts	−$13.42	−$8.84	−$22.26
Total employment impacts (number of jobs)	−153	−78	−231

regarding uncertain parameters, these figures provide reasoned estimates of economic impacts from reduced outdoor recreation caused by invasive weeds. However, given the relatively high value of the higher scenario estimate, we view the lower and middle scenario estimates (about −$6 million to −$12 million) as providing more defensible estimates of the likely range of annual effects.

We note that the width of the range of economic impacts may be somewhat overstated. This is because the lower estimates are derived by assuming that all the parameters jointly take on more "conservative" values and, similarly, the higher estimates depend on all the parameters simultaneously being "not conservative." We adopt this practice, however, to reflect the substantial uncertainty involved and in lieu of better information on the probability distributions of key parameters.

Much of the uncertainty in estimating current annual impacts can be traced to gaps in knowledge regarding current infestation rates. Therefore, ranges of current annual impact estimates are perhaps most useful as inputs for illustrating streams of potential economic impacts over future time horizons. Error in measuring current impacts then translates into a "starting point" error, which would shift the time horizon forward or backward. Table 7 presents estimates of the discounted present value of future flows of economic impacts. We predict impacts for four alternative average annual rates of expansion for nonindigenous invasive species: 5, 10, 15, and 20%. To be conservative, we use the lower scenario impact estimate from Table 4 ($5.9 million yr^{-1}) to predict economic impacts during a 5-yr period in the future. If either the middle or higher scenario estimates more accurately describe true annual impacts, then our predictions will understate future impacts. The degree of understatement may be substantial given that the middle annual estimate is about twice the lower scenario estimate.

Table 7. Predicted flows (over next 5 yr) of economic impacts from reductions in wildlife-based recreation by infestation expansion rate.

Mean annual infestation expansion rate	Present value streams of future economic impacts over next 5 yr[a]
5%	−$30 million
10%	−$33 million
15%	−$37 million
20%	−$41 million

[a] Discount rate = 4%. As the starting point for current annual economic impacts, we use the lower scenario estimate in Table 4 (U.S.$ 5.9 million yr^{-1}). Estimates in this table only reflect damages to wildlife-related recreation activities and exclude other lost economic values (e.g., lost grazing and ecosystem service flows such as soil retention, nutrient cycling, biodiversity) as well as out-of-pocket expenditures for weed control programs.

Two important implications can be derived from these results. First, for any given future time horizon, the present value stream of estimated impacts depends substantially on the average annual expansion rate for invasive species. Another way of saying this is that the future stream of impacts depends on how quickly society allows invasive weeds to spread. Second, uncertainty in future expansion rates is almost as important as uncertainty in current annual impacts (the starting point error to which we refer above). For example, if the true current annual impacts were actually twice as great as our estimate, then true impacts during the next 5 yr would also be twice as large as predicted. As shown in Table 7, uncertainty regarding the expansion rate (e.g., whether the true future rate will be 5 or 20%) leads to estimates that differ by almost 50%. During longer future time horizons (10 yr and longer), uncertainty regarding expansion rates is a more important source of overall uncertainty than the magnitude of the current starting point for annual estimated impacts (results not shown).

Given the importance of the expansion rate parameter, it is natural to inquire about the expected mean expansion rate for nonindigenous invasive species in Nevada and the arid West. As a reference point, Smith et al. (1999) examined the growth rates of a variety of different invasive weeds in diverse locations around the western United States. That study found an average expansion rate of approximately 24% per yr, with relatively high rates in early years and lower growth rates as an infestation matures. This figure is close to the estimated annual average growth (27%) of spotted knapweed in Montana since 1920 (Sheley et al. 1996). On the basis of this information, it is likely that most of the expansion rates modeled in Table 7 are conservative in the sense that they are lower than the intrinsic growth rates that many Western states will continue to witness barring major invasive species control efforts.

Our estimates that annual economic impacts stemming from recreation losses caused by nonindigenous weeds in Nevada are between −$6 million and −$12 million, conservatively, are striking given that Nevada ranks relatively low (compared with other states) in terms of the quantity of wildlife-related recreation. Nevada ranks about 47th overall in the total numbers of recreational days devoted to fishing, hunting, and wildlife watching (USFWS 1996). As a check on the results, note that although our estimated impacts are substantial in absolute terms, they are fairly modest in percentage terms. The lower scenario estimate (about −$6 million) represents only about 1% of current annual wildlife-related recreation expenditures in the state ($599.6 million). Therefore, given the sizeable economic values associated with outdoor recreation in the United States, even modest percentage losses due to nonindigenous weeds can translate into significant economic impacts.

There are several omissions, uncertainties, and limitations in our calculations. In fact, one of the main points of this study is that although researchers often lack the data desired to develop more precise estimates of weed damages, there are ways of constructing estimation approaches that provide preliminary findings on the rough ranges in which true impacts likely fall. Still, we indicate in this study a few of the main limitations to qualify the estimates. First, it is difficult to predict the substitution behavior that will take place as recreators respond to nonindigenous infestations. Recreator behavioral responses are quite site specific, and analysis of this factor requires expensive (and carefully constructed) primary research efforts. Because no rigorous analyses of this have ever been performed, our analysis cannot incorporate such information.

Second, in assigning ranges of values to uncertain parameters, we have attempted to be conservative (i.e., making assumptions that tend to lower the estimates of losses). As one example, the value of η is based on research conducted on a single invasive species (leafy spurge), with an infestation rate ($< 1\%$) that is lower than that for Nevada's total suite of nonindigenous weeds. It is reasonable to expect nonlinearity (beyond some point) in the relationship between infestation rate and recreation losses (i.e., increasing marginal losses), partly for the recreation site substitution considerations mentioned in the above paragraph. However, to be conservative and because of the lack of data to allow a defensible adjustment to this parameter, we have assumed linearity in the relationship. As another example, we have assumed conservatively that all in-state residents are able to respond to infestations by traveling to an alternative in-state site or otherwise spending their money within the state. For these and other reasons, it is reasonable to expect that our estimates of annual recreation losses may be conservative.

Third, in our calculations of future losses we have assumed that the expansion rate remains constant from year to year. However, there is some evidence to indicate nonconstant expansion rates for invasive weed infestations, with higher rates during the early years of infestations and lower rates as the infestations mature (Callihan and Evans 1991; Smith et al. 1999). Depending on the dynamic growth patterns of the particular weed species assessed, our assumption of constant growth rates may lead to either an understatement or an overstatement of future losses. In more detailed research, one might wish to incorporate empirical field data on infestation dynamics for the specific species at hand.

In addition, our estimates of economic impacts imposed by invasive weeds completely exclude any values besides wildlife-related recreation. Non–wildlife related issues include losses due to reduced forage for livestock and declines in crop productivity. Out-of-pocket costs incurred in weed management are also a completely separate item, and this article is not focused on control costs. Other lost values of prime importance include ecological functions and "service flows" (the maintenance of soil and water quality, watershed function, flood protection, nutrient cycling, biodiversity, ecological stability and resilience, reduced probability and size of wildfires, etc.). It is difficult (some would argue impossible) to estimate the value of maintaining healthy, functioning habitats in the Great Basin, Mohave Desert, Sierra Nevada, and other biogeographic provinces, apart from solely the direct use values associated with activities such as livestock grazing and recreation. Although not addressed in this article, it is reasonable to expect that the values of foregone ecological functions and services would exceed those of foregone direct human uses for the types of landscapes we consider.

Because little work has been done to quantify invasive weed damages on outdoor recreation, there are many useful potential avenues for future research. Several of these research avenues would address the different uncertainties and data gaps described above. These include more extensive weed-mapping efforts, better information on historical rates of spread by invasive species and host habitat type, and primary and site-specific studies of recreator responses to the invasion of landscapes by various nonindigenous species. The emerging literature on bioeconomic modeling of invasive weed economic impacts also offers approaches and data that in some cases are useful to practitioners (Eiswerth and Johnson 2002; Eiswerth and van Kooten 2002; Jones and Medd 2000). Each of these types of work will help improve the accuracy and precision with which researchers can estimate past economic losses and predict future impacts.[1]

Sources of Materials

[1] The contents of this manuscript do not necessarily reflect the views of Farm Service Agency, USDA, or any other organization with which any of the authors are affiliated.

Acknowledgments

The bulk of this research was conducted when all the authors were at the University of Nevada, Reno. Partial support was provided by the U.S. Department of Agriculture Cooperative Extension System's Integrated Pest Management Program. We thank Larry Leistritz for generously sharing information related to the work that he and his colleagues at North Dakota State University have conducted on the economic impacts of leafy spurge.

Literature Cited

Bangsund, D. A., F. L. Leistritz, and J. A. Leitch. 1999. Assessing economic impacts of biological control of weeds: the case of leafy spurge in the northern Great Plains of the United States. J. Environ. Manag. 56: 35–43.

Bell, C. E. 1996. Saltcedar: A Non-native Invasive Plant in the Western U.S. Berkeley, California: University of California Cooperative Extension Service. Pp. 1–4.

Callihan, R. and J. Evans. 1991. Weed dynamics on rangeland. Pages 55–61 *in* L. F. James, J. O. Evans, M. E. Ralphs, and R. D. Childs, eds. Noxious Range Weeds. Boulder, CO: Westview.

D'Antonio, C. M. and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annu. Rev. Ecol. Syst. 3:63–87.

Eiswerth, M. E., S. Donaldson, and W. S. Johnson. 2000. Potential environmental impacts and economic damages of Eurasian watermilfoil in western Nevada and northeastern California. Weed Technol. 14:511–518.

Eiswerth, M. E. and W. S. Johnson. 2002. Managing nonindigenous in-

vasive species: insights from dynamic analysis. Environ. Resour. Econ. 23:319–342.
Eiswerth, M. E. and G. C. van Kooten. 2002. Uncertainty, economics, and the spread of an invasive plant species. Am. J. Agric. Econ. 84:1317–1322.
Jones, R. E. and R. W. Medd. 2000. Economic thresholds and the case for longer term approaches to population management of weeds. Weed Technol. 14:337–350.
Larson, L. L. and R. L. Sheley. 1994. Ecological relationships between yellow starthistle and cheatgrass. Pages 92–94 *in* S. B. Monsen and S. G. Kitchen, eds. Proceedings of Ecology and Management of Annual Rangelands. Fort Collins, CO: USDA Forest Service General Technical Report. INT-GTR-313.
Leistritz, F. L., F. Thompson, and J. A. Leitch. 1992. Economic impact of leafy spurge in North Dakota. Weed Sci. 40:275–280.
Leitch, J. A., F. L. Leistritz, and D. A. Bangsund. 1996. Economic effect of leafy spurge in the upper Great Plains: methods, models, and results. Impact Assessment 14:419–433.
Mack, R. N. 1981. Invasion of *Bromus tectorum* L. into Western North America: an ecological chronicle. Agro-Ecosystems 7:145–165.
Madsen, J. D. 1997. Methods for management of nonindigenous aquatic plants. Pages 145–171 *in* J. O. Luken and J. W. Thieret, eds. Assessment and Management of Plant Invasions. New York: Springer-Verlag.
Madsen, J. D., J. W. Sutherland, J. A. Bloomfield, L. W. Eichler, and C. W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies. J. Aquat. Plant Manag. 29:94–99.
McKell, C. M., J. P. Robison, and J. Major. 1962. Ecotypic variation in medusahead, an introduced annual grass. Ecology 43:686–698.
Miller, R. and P. Blair. 1985. Input-Output Analysis: Foundations and Extensions. Englewood Cliffs, NJ: Prentice-Hall. Pp. 6–39.
Minnesota IMPLAN Group Inc. 2000. IMPLAN Professional™, Version 2.0, Social Accounting & Impact Analysis Software. Stillwater, MN: Minnesota IMPLAN Group. Pp. 1–418.
Newroth, P. R. 1985. A review of Eurasian water milfoil impacts and management in British Columbia. Pages 139–153 *in* Proceedings of the First International Symposium on Watermilfoil (*Myriophyllum spicatum*) and Related Haloragaceae Species, July 23–24, 1985, Vancouver, British Columbia, Canada. Vicksburg, MS: Aquatic Plant Management Society.
Olson, B. E. 1999. Impacts of noxious weeds on ecologic and economic systems. Pages 4–18 *in* R. L. Sheley and J. K. Petroff, eds. Biology and Management of Noxious Rangeland Weeds. Corvallis, OR: Oregon State University Press.
Roche, B. F., Jr. and C. T. Roche. 1991. Identification, introduction, distribution, ecology, and economics of *Centaurea* species. Pages 274–291 *in* L. F. James, J. O. Evans, M. E. Ralphs, and R. D. Childs, eds. Noxious Range Weeds. Boulder, CO: Westview.
Roche, B. F., Jr. and C. T. Roche. 1999. Diffuse knapweed. Pages 217–230 *in* R. L. Sheley and J. K. Petroff, eds. Biology and Management of Noxious Rangeland Weeds. Corvallis, OR: Oregon State University Press.
Roche, C. T. and D. C. Thill. 2001. Biology of common crupina and yellow starthistle, two Mediterranean winter annual invaders in western North America. Weed Sci. 49:439–447.
Rosentrater, R. 1994. Displacement of rare plants by exotic grasses. Pages 170–175 *in* S. B. Monsen and S. G. Kitchen, eds. Proceedings of Ecology and Management of Annual Rangelands. Fort Collins, CO: USDA Forest Service General Technical Report. INT-GTR-313.
Sala, A., S. D. Smith, and D. A. Devitt. 1996. Water use by *Tamarix ramosissima* and associated phreatophtyes in a Mojave Desert floodplain. Ecol. Appl. 6:888–898.
Sheley, R. L., J. M. Hudak, and R. T. Grubb. 1999a. Rush skeletonweed. Pages 308–314 *in* R. L. Sheley and J. K. Petroff, eds. Biology and Management of Noxious Rangeland Weeds. Corvallis, OR: Oregon State University Press.
Sheley, R. L., J. S. Jacobs, and M. L. Carpinelli. 1999b. Spotted knapweed. Pages 350–361 *in* R. L. Sheley and J. K. Petroff, eds. Biology and Management of Noxious Rangeland Weeds. Corvallis, OR: Oregon State University Press.
Sheley, R. L., M. E. Manoukian, and G. Marks. 1996. Preventing noxious weed invasion. Rangelands 18:100–101.
Smith, H. A., W. S. Johnson, J. S. Shonkwiler, and S. R. Swanson. 1999. The implications of variable or constant expansion rates in invasive weed infestations. Weed Sci. 47:62–66.
U.S. Bureau of the Census. 2000. Annual Benchmark Report for Retail Trade, January 1990 to December 1999, Current Business Reports Series, BR/99-A. Washington, D.C.: U.S. Bureau of the Census, 34 p.
U.S. Department of Commerce. 2001. 2000 Personal Income, Industry Earnings, and Industry Employment for Nevada Counties. Washington, D.C.: Bureau of Economic Analysis, Regional Economic Information System. Table SA25.
[USFWS] U.S. Fish and Wildlife Service. 1996. 1996 National Survey of Fishing, Hunting and Wildlife-Associated Recreation. Washington, D.C.: U.S. Fish and Wildlife Service. Pp. 105–115.
Whitson, T. D. 1999. Russian knapweed. Pages 315–322 *in* R. L. Sheley and J. K. Petroff, eds. Biology and Management of Noxious Rangeland Weeds. Corvallis, OR: Oregon State University Press.
Young, J. A. and W. S. Longland. 1996. Impact of alien plants on Great Basin rangelands. Weed Technol. 10:384–391.
Young, J. A., E. Martens, and N. E. West. 1992. Germination of bur buttercup seeds. J. Range Manag. 45:358–362.

Received January 16, 2004, and approved August 12, 2004.